

Magnetically Actuated Propellant Orientation

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In a low-g environment, acquisition of vapor-free propellant is complicated by the indeterminate location of bulk liquid with

respect to the tank outlet. Proper design of engine feed or propellant transfer systems requires methods to control liquid orientation and an understanding of fluid motion in response to disturbances and imposed accelerations. Traditional approaches for controlling and positioning cryogenic liquids, such as periodic thruster firings and capillary retention devices, exhibit several drawbacks that could be mitigated by employing systems which exploit the inherent paramagnetism of liquid oxygen (lox) and diamagnetism of liquid hydrogen (LH₂). With the advent of lightweight, high-temperature superconductors and high-flux density, rare-Earth magnets, the use of

magnetic fields to control large fluid quantities in microgravity appears feasible, and could enable low-g settling, venting, fill and acquisition without the need for capillary retention systems or propulsive firings. Some of these potential applications are shown in figure 34.

This project is currently evaluating the feasibility and practicality of magnetically actuated propellant orientation (MAPO) for spacecraft applications. The scope has been restricted to lox primarily because:

- Control of lox offers the nearest term application of MAPO technology;

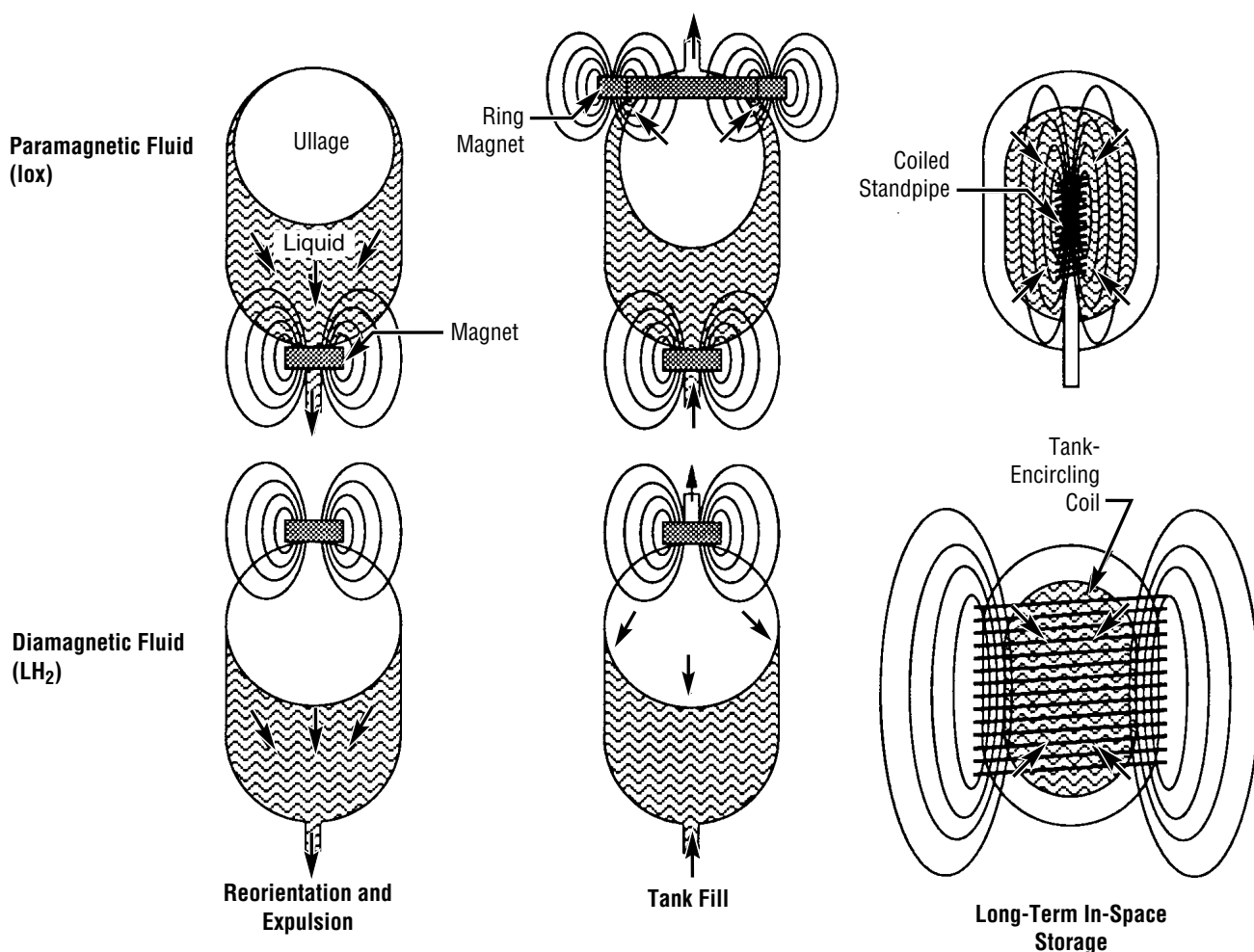


FIGURE 34.—Low-gravity fluid orientation concepts using magnetic fields.

- The magnetic properties of paramagnetic fluids are well known; and
- Lox behavior has been tested before in low-g on a laboratory scale.

One of the primary objectives is to determine the range of magnetic field strengths required to perform reorientation and maintain liquid orientation during tank fill and expulsion. This range will provide a basis for evaluating whether these magnetic field requirements fall within the capabilities of current or anticipated superconducting magnet technology.

The project involves low-g experiments using NASA's reduced gravity workshop (a KC-135 aircraft). All experiments employ several subscale hardware setups, one of which is shown in figure 35, and a noncryogenic ferrofluid that simulates the paramagnetic behavior of lox. The ferrofluid is a commercially available water-based solution containing a suspension of extremely fine ferrous particles. Several properties of this fluid (i.e., particle density, viscosity and surface tension), along with tank diameter, flowrates and magnetic field intensities, are being scaled to model lox behavior in a spacecraft-type application. Design and assembly of the test articles has been completed and one flight aboard the KC-135 was made in September 1995. Three other flight tests will be conducted in September and October 1996 and February of 1997.

Scaling analyses have shown that magnets in the size range of 1 to 10 Tesla should be adequate for propellant reorientation in a full-scale lox application. These results, however, are rather limited since the fields can typically assume very complicated geometries, which are difficult to characterize in terms of dimensionless groupings. Consequently, another aspect of this activity is focused on modifying an existing computational fluid dynamic (CFD) to include the body and surface forces arising from the interactions between the fluid and magnetic field. This will provide a more rigorous means of assessing fluid behavior, and will enable the modeling of more complicated



FIGURE 35.—Low-gravity fluid orientation and transfer tests aboard KC-135 aircraft.

field geometries and advanced concepts, such as liquid hydrogen. Videotaped recordings of fluid motions taken from the low-g tests will be used to validate the revised CFD model.

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Biographical Sketch: Dr. George Schmidt is a lead engineer in the Systems Evaluation and Analysis Branch of MSFC's Propulsion Laboratory. He received a B.S. and M.S. in mechanical engineering from Stanford University in 1981, an M.S. in aerospace engineering from the University of Washington in 1985, and a Ph.D. in mechanical engineering from the University of Alabama in Huntsville in 1993. His team

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